

# CAAP Quarterly Report

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Contract Number: *DTPH5614HCAP04*

Prepared for: *Arthur Buff, Project Manager, PHMSA/DOT*

Project Title: *Embedded Passive RF Tags towards Intrinsically Locatable Buried Plastic Material*

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For quarterly period ending: *January 10, 2017*

## **Business and Activity Section**

### **(a) Generated Commitments**

**Project abstract:** Accurate and reliable locating, identifying and characterizing the buried plastic pipes from the ground surface in reducing the likelihood of hit them is critical and imperative to reduce the pipeline incidents. In this collaborative research, a new harmonic radar (frequency doubling) mechanism for smart RF tags design that can detect plastic pipes deeply buried in various soils conditions will be investigated, achieved through efficient tags and highly sensitive readers design, and coupled with intelligent signal processing. The proposed low-cost, small thin-film form passive RF tags can directly be embedded in plastic pipes. It will be able to withstand high temperature processing of plastics and stress involved with horizontal tunneling/drilling of buried pipes. The embedded RF tags have the capability to not only precisely locate the buried plastic pipes, but also have integrated sensing functionality, which can measure the strain-stress changes in the plastic materials. Finally, the vast amount of acquired sensing data from individual tags will be integrated to the advanced signal processing for better data categorization and mining. An innovative prognostics framework for better asset life-cycle management will be developed.

A complete solution is needed that helps in identifying individual buried pipes, their precise location, determining their integrity and sensing for leaks. Buried pipes are expected to have a lifetime of greater than 30 years that are designed to carry a range of liquid and gaseous materials. Among the many pipe technologies, demand for plastic pipes is growing largely because of their low-cost and potential for long life time. Any tags or sensors that are incorporated within these pipes should be able to withstand harsh conditions with a lifetime meeting or exceeding that of the pipes, and should be battery free (passive tag). Furthermore, the overall system should be compact, low-cost, and easy to operate. With advanced techniques to bury the pipes using tunneling approaches it is necessary that tags withstand the associated stress and handling during construction work. Typically, the pipes are buried 3 feet or deeper in the ground and thus the reader should be able to interrogate the tags at these and at higher depths (greater than 5ft is desired).

As summarized in Introduction section, significant advances have been made in the area of electronic tagging of buried objects. However, most of these tags are an afterthought as they are not

integral part of the infrastructure. These tags are typically large and are buried along with the objects. This is simple if open trenching is carried out. However, for plastic pipes that are buried using tunneling this approach will not suffice without making the tags an integral part of the plastic pipe. Furthermore, no RF tags are commercially available that will allow in sensing of the environment and the integrity of the buried object during its life time. Smart RF tag designs are necessary as power harvesting and storage techniques will also have limited life time as the rechargeable batteries (or capacitors) and the associated circuit (e.g., piezo power harvester) will have a limited lifetime. Meanwhile, no advanced data processing algorithms are available for optimally manage and use the vast amount of information embedded into the received RF signals from the proposed new tags. Under this three-year project, the specific technical objectives/goals of the proposed research are:

- 1) Design and development of new passive harmonic radar based smart RF tags with long range detection guided by industry partners;
- 2) Design robust and miniature tags such that they can directly be embedded in plastic pipes during manufacturing;
- 3) Investigate on-tag strain-stress sensing capabilities and efficient data transmission;
- 4) Investigate new massive RFID data mining, processing and classification algorithms with experimental testing;
- 5) Develop a Bayesian Learning based pipeline hazardous prognostics methodology using discrete sensing data;
- 6) Intrinsically locatable pipe materials demonstration and field testing using representative pipe specimens with GPGPU acceleration.

Another equally important objective of this proposed research is to engage MS and PhD students who may later seek careers in this field by exposing them to subject matter common to pipeline safety challenges. Since the project being kicked off, three PhD students from both universities and several MS students have been recruited and trained through this CAAP program and apply their engineering disciplines to pipeline safety and integrity research. The PIs think the educational component is a very important part of the CAAP project and will integrate with research activities with various educational activities to prepare the next generation engineers for gas and pipeline industry. The educational and research impacts sponsored by CAAP has been recognized within the university (see *support letter 3 from Associate Vice Chancellor of university*) and nationally (Two current CAAP-funded students at CU haven been recognized at ASNT annual research symposiums in 2014 and 2015). Specific educational objectives and goals are:

- 1) Guide and train graduate students at University of Colorado-Denver and Michigan State University for the pipe integrity assessment and risk mitigation;
- 2) Integrate with existing mechanisms for undergraduate research at University of Colorado-Denver and Michigan State University for early exposure of pipe industry research to potential engineers;
- 3) Improve the current curriculum teaching at University of Colorado-Denver (ELEC5644 Nondestructive Evaluation and ELEC3817 Engineering Probability and Statistics) and Michigan State University (ECE802-1 Microwave and Millimeter Wave Circuits and ECE802-2 Electronic Systems Packaging) using the achievement from the proposed research;
- 4) Invite pipe industry expert (see support letters later in this proposal) to deliver seminar/workshops to undergraduate/graduate students about the challenges and opportunities in gas and pipeline industry;
- 5) Encourage the involved students to apply internships at DOT and industry to gain practical experiences for the potential technology transfer of the developed methodologies.

The above-mentioned goals and objectives of the proposed Competitive Academic Agreement Program (CAAP) project will be well addressed and supported by the proposed research tasks.

Development, demonstrations and potential standardization to ensure the integrity of pipeline facilities will be carried out with the collaborative effort among different universities and our industry partners. The quality of the research results will be overseen by the PIs and program manager and submitted to high-profile and peer-reviewed journals and leading conferences. The proposed collaborative work provides an excellent environment for integration of research and education as well as tremendous opportunities for two universities supported by this DOT CAAP funding mechanism. The graduate students supported by this CAAP research will be heavily exposed to reliability and engineering design topics for emerging pipeline R&D technologies. The PIs have been actively encouraging students to participate in past and ongoing DOT projects and presented papers at national and international conferences. Students who are not directly participating in the CAAP project will also benefit from the research findings through the undergraduate and graduate courses taught by the PIs and attending university-wide research symposium and workshop, e.g. RaCAS at CU-Denver. The proposed research involves pipeline industry to validate and demonstrate scientific results and quantify engineering principles by working closely with industry partners. They will also collaborate with the CAAP team on this research which may include but is not limited to information exchange, mutual meetings, providing CU and MSU with appropriate technical support for the target application.

## (b) Status Update of Past Quarter Activities

### Task 1 – Experimental setup at University of Colorado, Denver

#### A: Distance Estimation

A close estimation of pipe's burial depth was introduced in last quarter. Theoretically, the phase information of signal can be used to approximate the distance between the interrogator and RFID tag. In this quarter, experiments have been performed to confirm the theory and the distance between a transmitter and a receiver is estimated. Fig.1 shows the block diagram of conducted experiment.

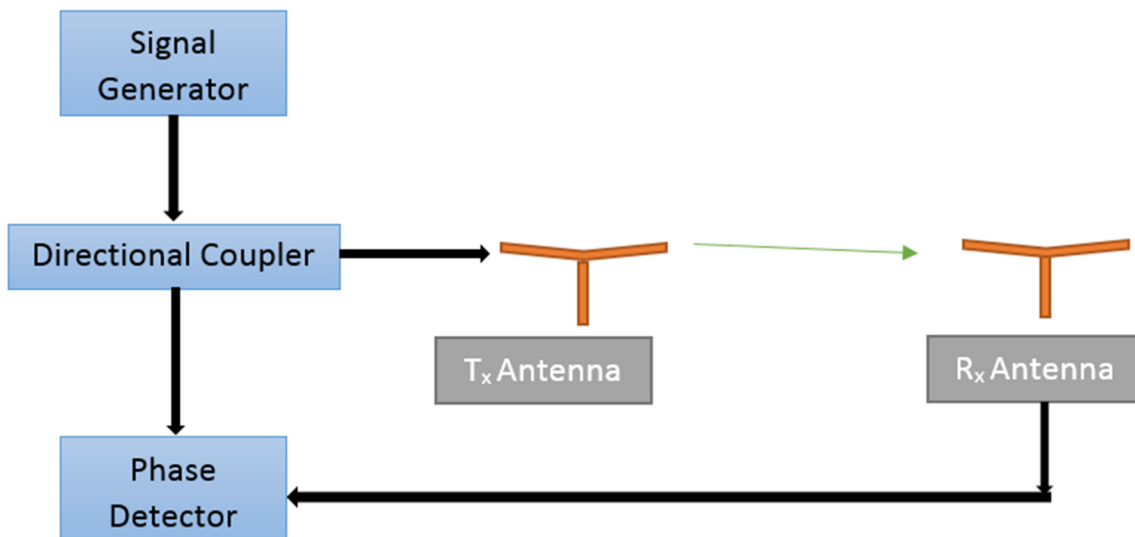


Fig.1 Phase measurement block diagram

The phase detector (AD8302) gives an output voltage in accordance to the phase difference between two input signals. The reference signal is a part of the signal fed into the transmitting antenna and the received signal is used for checking the phase difference.

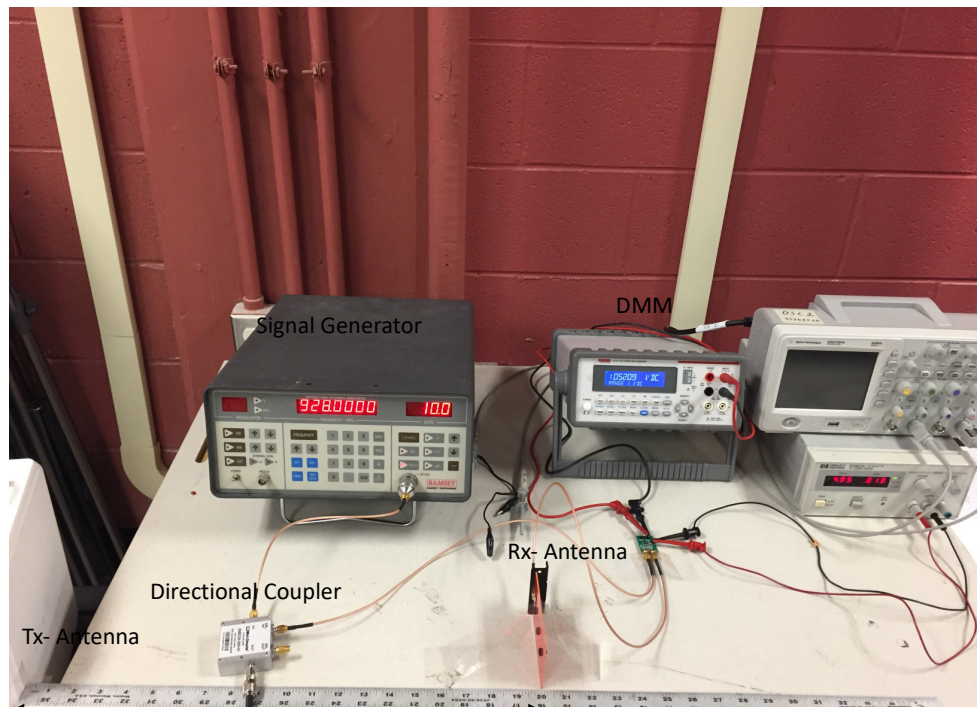


Fig.2 Phase measurement setup

The change in voltage (phase) vs distance is shown in Fig. 3a. The output voltage representing phase changes over distance and repeats the pattern with each wavelength.

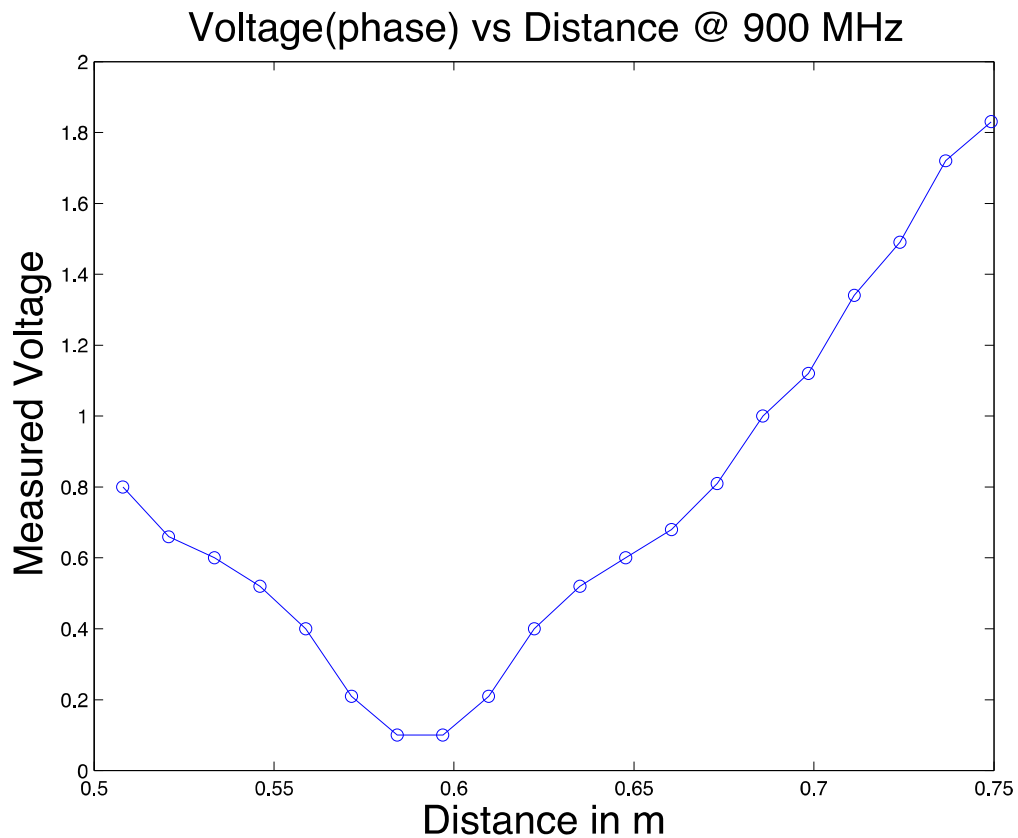


Fig.3a Phase vs Distance at 900-MHz

The phase difference between two signals are recorded at five different frequencies by keeping a constant separation in between transmitter and receiver. The measured voltages and translated phase are shown in Table 1.

FREQUENCY	MEASURED VOLATGE (V)	TRANSLATED PHASE (DEGREE)
928-MHZ	1.05+-0.02	17.25
923-MHZ	1.01+-0.02	13.85
919-MHZ	0.97+-0.02	12.70
913-MHZ	0.87+-0.02	4.60
902-MHZ	0.75+-0.02	1.30

Table 1 Measured Phase

The separation between transmitter and receiver is computed using the distance estimation algorithm. The measured phases get translated into 0.564m, which is a close estimation to the actual distance (0.5m) between transmitter and receiver. The occurrence of the small offset may be due to the presence of the noise in the system. Additional experiment is also performed with the separation of 1m and translated phases are shown in Table 2. The computed distance was 1.27-m.

FREQUENCY	MEASURED VOLATGE (V)	TRANSLATED PHASE (DEGREE)
928-MHZ	1.32+-0.02	33.45
923-MHZ	1.12+-0.02	25.85
919-MHZ	1.1+-0.02	20.15
913-MHZ	1.06+-0.02	17.85
902-MHZ	0.81+-0.02	1.45

Table 2 Measured Phase

## B: Stress Simulation

The on-tag sensing capabilities of the system also involves collecting quantitative information about local environment like moisture, external stress over pipe, etc. The effects on plastic pipe due to external stress are studied and a model of quantitatively defining the stress is presented. Harmonic RFID tags embedded in plastic pipes also experience the same stress and change its properties accordingly. COMSOL Multiphysics simulation tool is used to check and validate the problem. For simplicity, a simple patch antenna (1800 MHz) is being designed, shown in Fig. 4. The  $S_{11}$  plot without any applied stress is also shown in Fig.5 for reference.

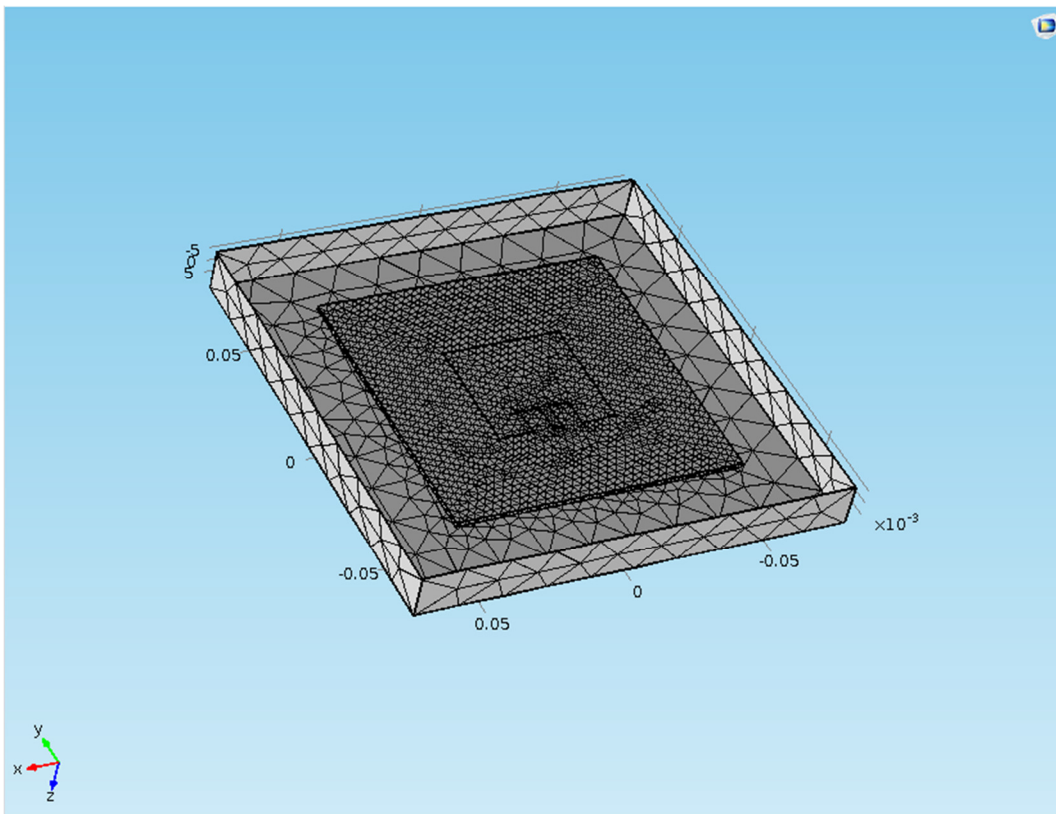


Fig. 4 Modeled Antenna

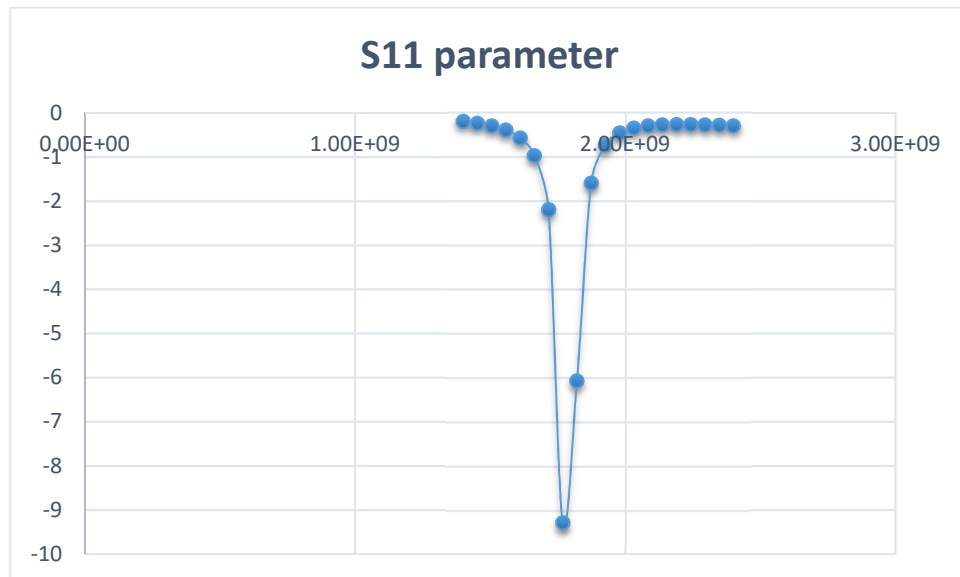


Fig. 5  $S_{11}$  Frequency response of antenna

The study of solid mechanics is also added in the simulation model and a load of 1000N is applied over the whole substrate. The changes are probed with the applied stress and the results are shown in Fig. 6.

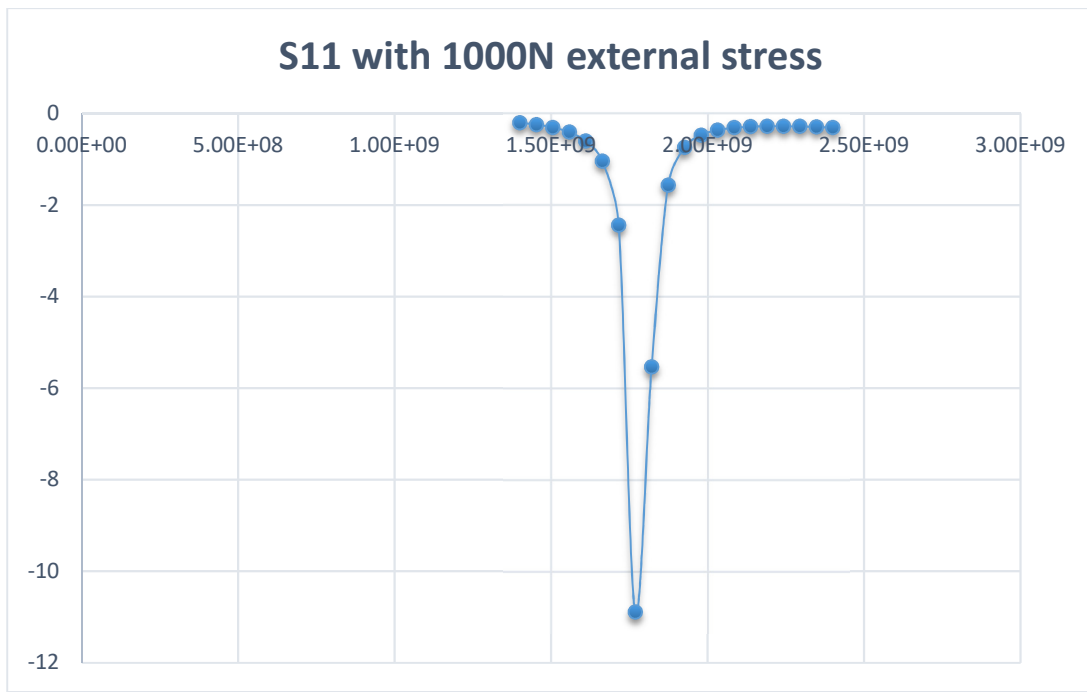


Fig. 6  $S_{11}$  with applied stress (1000 N)

The resonance of the antenna shifts with the stress can be clearly seen. Fig.7 shows some more simulations with different stress level and it is observed that the antenna can also be used to monitor any potential damage to pipe due to local stress.

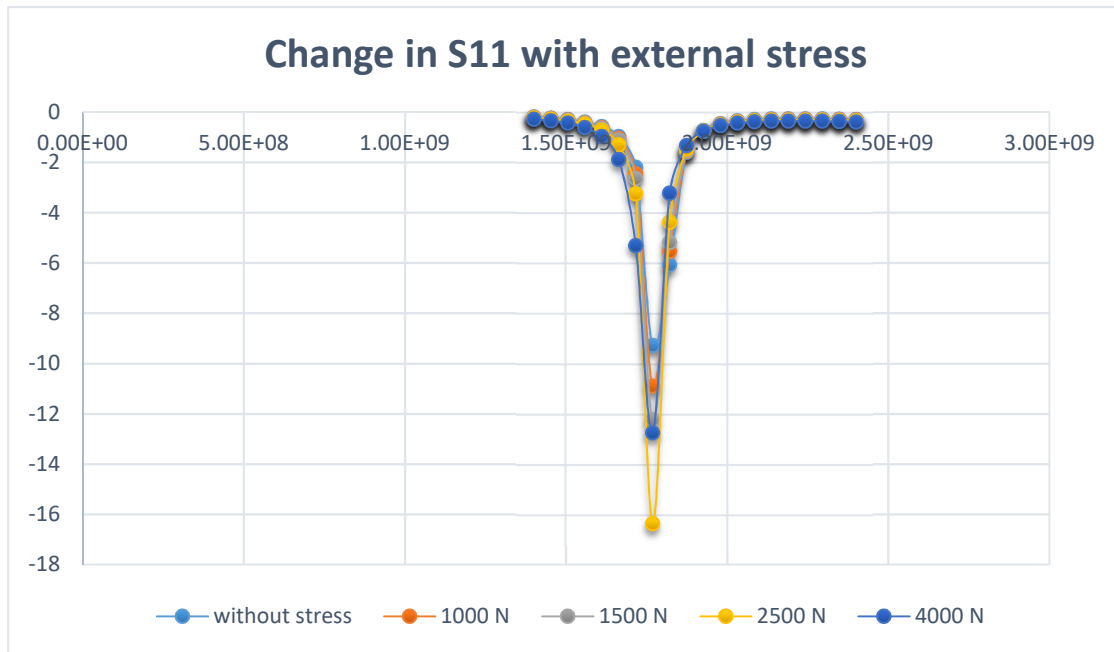


Fig. 7  $S_{11}$  with different level of applied stress

### C: Additional Experiment

An experiment with 900-MHz (harmonic 1800 MHz) tag system is performed using the setup at CU Denver. A patch antenna is designed to receive the harmonic signal from tag. Both tag and receiver are shown in Fig. 8.

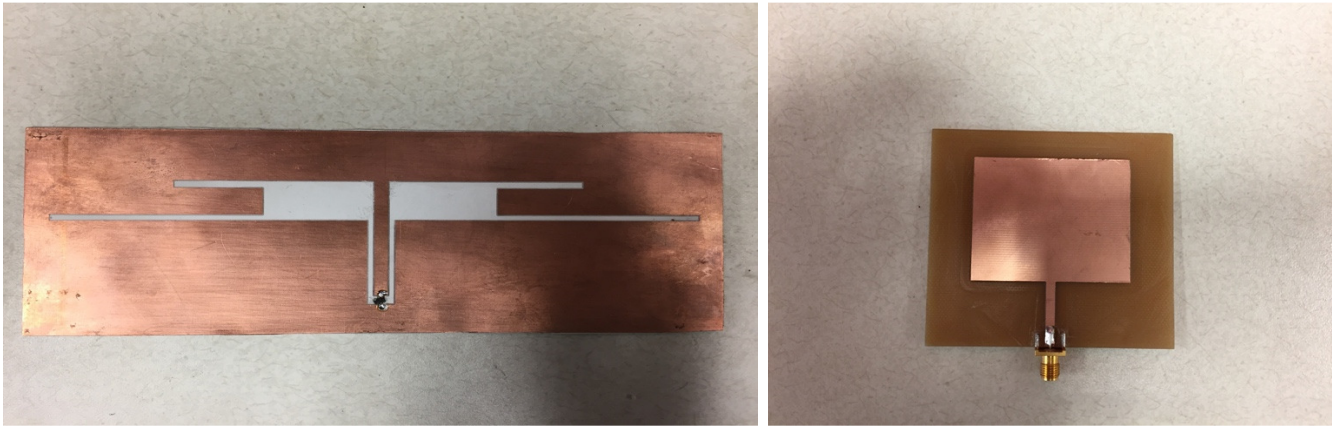


Fig. 8 Tag and Receiver Antenna

The power received in air with respect to distance is plotted in Fig. 9.



Fig. 9 Power vs Distance in AIR

## Task 2 – Design and development of passive harmonic radar based smart RF tags

The task 2 demonstrates the improved version of



### **(c) Planned Activities for the Next Quarters**

Besides the planned activities mentioned in section (b), here is the future work for the next quarter:

#### CU: ON-TAG SENSING, DATA MINING AND PROCESSING SETUP:

- RFID communication protocol will be addressed
- On tag sensing capabilities will be explored
- The implementation of tags over pipes will be investigated

#### MSU: NEW PASSIVE RFID TAG DESIGN:

- In the next phase, design of